Coulomb Sink: a novel Coulomb effect on stability of nanoclusters on semiconductor surfaces

Feng Liu
University of Utah

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The Coulomb effect is ubiquitous in physics, chemistry, and biology. One well-known manifestation of the Coulomb effect on stability of a cluster is Coulomb explosion. It is defined classically by the Rayleigh instability limit, above which an excessively charged cluster becomes unstable and explodes into smaller fragments. Coulomb explosion, a century-old concept, has been extensively explored in the study of nanoclusters. Recently, Professor Feng Liu at the University of Utah proposed a new concept of “Coulomb sink” [*Phys. Rev. Lett.* ***93****, 106102, (2004*)], elucidating a novel manifestation of the Coulomb effect on stability of metal nanoclusters on semiconductor surfaces, as illustrated in Fig. 1. This new concept has also been demonstrated experimentally by the growth of Pb nanoclusters under STM charging on Si surface, as shown in Fig. 2.

Coulomb sink, leading to cluster agglomeration, is effectively a reversed process of Coulomb explosion, leading to cluster fragmentation (Fig. 1). *It provides a unique and effective method for manipulating growth of metal nanoclusters on semiconductor or insulator surfaces with a unprecedented size control up to millions of atoms* (Fig. 2). Two graduate students supported by NSF (DMR-0307000) have participated in the study of the “Coulomb sink” effect.

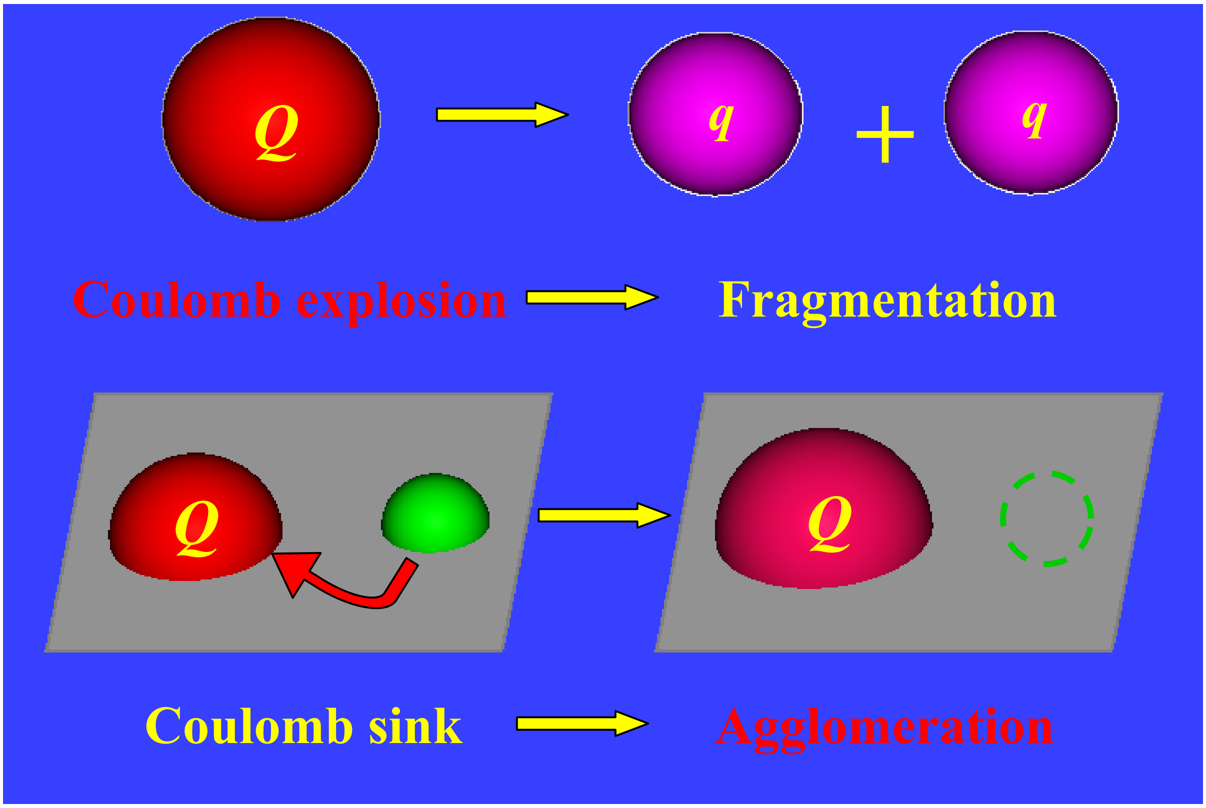

Fig. 1. Schematic illustration of Coulomb sink (lower panel) vs. Coulomb explosion (upper panel). In Coulomb explosion, a charged (Q) nanocluster (red) explored beyond the Rayleigh instability limit into smaller fragments (pink), each carrying less charge (q), to release Coulomb energy. In Coulomb sink: a charged (Q) metal nanocluster (red) on a surface may not explode, but instead grows its size, by "sinking" atoms from its neighboring (uncharged) neutral nanoclusters (green), to reduce its Coulomb energy. It is shown that charging reduces the chemical potential of the charged nanocluster relative to its neighboring neutral clusters. Consequently, it grows at the expense of its neighbors via the cluster coarsening process. Since one can selectively charge any chosen cluster with a controllable amount of charge, *Coulomb sink provides a unique and effective method for manipulating growth of metal nanoclusters with a size control up to millions of atoms.*

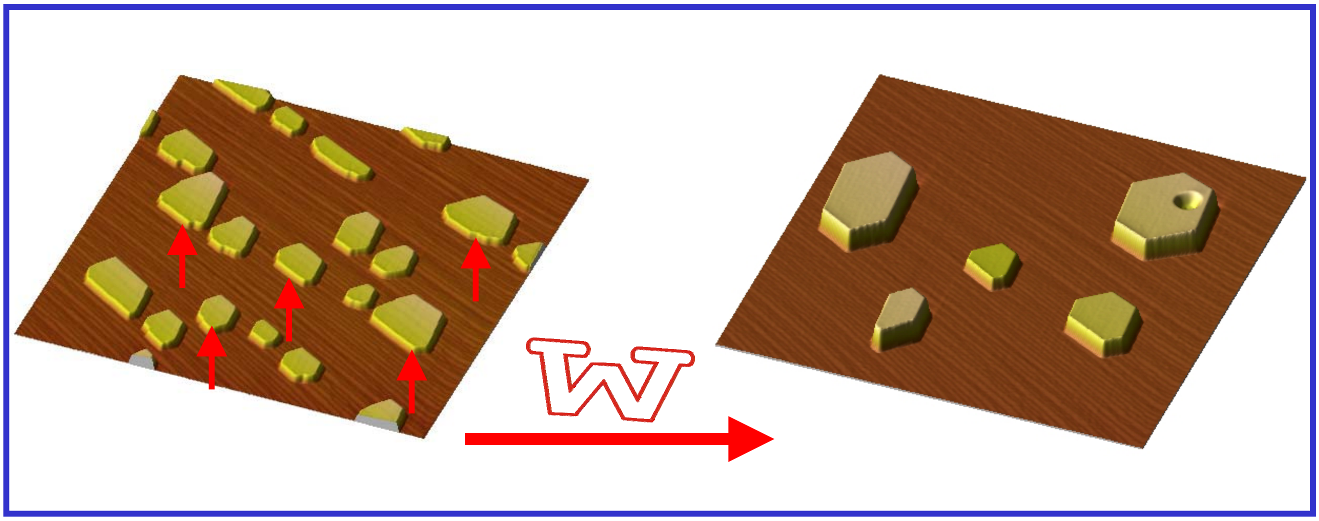

Fig. 2. An experimental demonstration of the Coulomb sink phenomenon, via growth of Pb nanoclusters (in distorted hexagonal mesa shape) on Si(111) surface, imaged by scanning tunneling microscope (STM). Five selected Pb clusters (as marked by red arrows in the left figure) are charged by STM. As a result, these five clusters grows at the expense of their neighboring uncharged (neutral) clusters, forming a logo “W” on the right. It is confirmed that the number of atoms in the process is conserved, indicating that the growth of the five charged clusters is achieved by “sinking” all the atoms from their uncharged neighbors via the “Coulomb sink” effect in the cluster coarsening process. The total number of atoms involved in this manipulation process is over 10 millions of atoms. The experimental images are provided by Prof. Q.K. Xue and J.F. Jia, Institute of Physics, Chinese Academy of Science.